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Visibility Changes in Ohio, Kentucky, and Tennessee From 1962 to 1969

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ABSTRACT—Previous studies of changes in visibility over a period of years have indicated either a general trend toward better horizontal visibilities or no change. In this study, visibility, relative humidity, wind direction, and other related data from three National Weather Service Offices (Akron, Ohio; Lexington, Ky.; Memphis, Tenn.) are used to determine changes in daylight visibilities during the summer seasons of 1962–69. Analyses of the data indicate that the percent of restricted visibility was greater during the period 1966–69 than during the period 1962–65 both before and after adjustment for the effects of location, time of day, humidity, and wind.

1. BACKGROUND

In recent years, atmospheric scientists have displayed a growing interest in visibility restrictions and the aerosols which affect visibility. By utilizing hourly observations of horizontal surface visibility taken at field offices of the National Weather Service (NWS), numerous investigators have studied trends in visibility over given periods of record in an attempt to determine whether these trends might be related to atmospheric pollution or might be some indication of inadvertent weather modification.

To properly use the available visibility data, the researcher must understand the rules and procedures an observer follows when he makes a visibility observation. Where practicable, such observations are to be made with reference to a plane 6 ft above the ground (U.S. Departments of Commerce, Defense, and Transportation 1971). Observations taken from the roof of a building or at airport control towers are exceptions to this standard. Visibility, as recorded by NWS personnel, is called prevailing visibility and is defined as the greatest horizontal visibility prevailing throughout at least half of the horizon circle at which it is just possible to see and identify with the unaided eye (a) prominent dark objects in the daytime and (b) unfocused lights of moderate intensity at night. Robinson (1968) presented a detailed review of observational problems, mathematical concepts, and other factors related to visibility data.

Holzworth and Maga (1960) presented a method for analyzing the trend in visibility. This method consisted of fitting linear trend lines to plots of annual percent frequencies of visibilities in specified ranges. Net changes and shifts among the visibility classes were then proportional to the slopes of the lines. To determine the general visibility trend in the United States, Holzworth (1962) compared the mean monthly percent frequencies of *all* hourly visibilities less than 7 mi at 28 locations for two periods of record separated by about 15–20 yr. The periods of record compared were 1930–38 and 1955–61. Based on a sample of 336 comparisons, Holzworth found that low visibilities (less than 7 mi) were more frequent in the later period in only 89 of the comparisons. Beebe (1967) compared tabulations of hours with visibility restrictions due to smoke or haze in January 1945 with similar data for January 1965 for eight locations, This study showed that visibility restrictions due to smoke and haze decreased from a combined total of 1,774 hr in 1945 to 326 hr in 1965, which is a change of 82 percent between the two periods. One explanation for these apparent trends toward improving visibility has been the widespread fuel conversion (i.e., from coal to gas or oil) that took place after World War II.

Green and Battan (1967) reported an abrupt improvement in the Phoenix, Ariz., 1100- and 1700-MST visibilities in the 0–15- and 16–30-mi ranges; but they attributed this improvement that occurred in the late 1950s to revisions in local procedures for observing visibility. In this same report, Green and Battan showed that the 17-yr trends (1949–65) in the 1100- and 1700-MST visibilities at Tucson, Ariz., were toward more frequent "poor" visibilities (i.e., more visibilities in the 0–15-mi range). Lea (1970*a*, 1970*b*) has studied September midday visibilities for the period 1950–69 at two locations near Los Angeles, Calif. Results from Lea's study indicate that September midday visibilities on San Nicolas Island have not undergone any significant change from 1950 through 1969, but visibilities at Point Mugu have declined over the past two decades. Lea attributes the decline of Point Mugu's September noon visibilities "to the increasing prevalence of air pollution."

2. INTRODUCTION

During the late 1960s, aviation pilots and others visiting the NWS Office at the Akron-Canton Airport, Ohio, claimed the haze layer was becoming a serious problem, especially east of the Mississippi River. Because of these notations, one of us (Ritter) compiled, from Akron-Canton Airport data collected beginning in 1949, the

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FIGURE 1.—Total hours that the visibility at the Akron-Canton Airport was 7 mi or more for the summer months (June–September).

monthly total number of all hours the visibility was greater than or equal to 7 mi. Monthly means over 20 yr were calculated from these data. From the plots of monthly frequencies of visibilities equaling or exceeding 7 mi, it was apparent that warm season visibilities in particular had changed during the 1960s. Because of this, a plot of the total number of all hours with visibilities equal to or greater than 7 mi for the summer periods (June through September) of 1954–69 was made (see fig. 1). This figure shows a drastic decrease in "good" summer visibilities between 1965 and 1969 and this prompted the authors to undertake an investigation of visibility changes during the 1960s at Akron, Ohio, and at two other comparative Weather Service Offices (WSOs) that would best meet several criteria. It was thought that, ideally, these other WSOs should: (1) have no significant change in weather observing sites, (2) be at least several miles from major local pollution sources, (3) be generally "upwind," that is, south to west of Akron, (4) have been free from substantial changes of weather observing staffs or local observing practices, (5) be in different administrative regions of the NWS (in case there were subtle unknown differences in observing practices), and (6) have a homogeneous surface wind record. The WSOs selected were Lexington, Ky., and Memphis, Tenn.

The Akron-Canton Airport is located about midway between Akron and Canton. Rolling terrain is in the immediate area. Air moving toward the airport from the south-southeast, southwest, and northwest through north directions traverses urban areas with considerable industry. Lexington's airport is west-northwest of downtown Lexington. Terrain in the Lexington area is gently rolling, with the elevation varying between 900 and 1,050 ft above mean sea level. The Memphis International Airport is about 8 mi south of the downtown area. Only north through northeast winds, which are relatively infrequent in summer, move across much of the Memphis urban area before reaching the airport.

3. SELECTION OF DATA FOR ANALYSIS

For our study, we felt that wind direction and speed, precipitation, and relative humidity are the meteorological variables most likely to influence surface horizontal visibility. These meteorological data are available in automatic processing form for all hours (starting in 1948) through December 1964; but beginning Jan. 1, 1965, card punching of hourly observations was reduced to every third hour, beginning with 0100 EST. To avoid mixing day and night visibility observations (i.e., dark objects versus unfocused lights), we decided to limit our study to the daylight summer (June–September) hours of 0700, 1000, 1300, 1600, and 1900 EST. A review of station histories showed that installation of modern wind sensors at or near the standard height of 20 ft was not completed until Apr. 27, 1962. Accordingly, to assure homogeneity of all wind data, the authors chose to limit this visibility study to the summer seasons of 1962 through 1969.[5]

Three trivariate tables were prepared from data for each airport location (Akron, Lexington, and Memphis) by the National Climatic Center (NCC). These tables served to stratify the data on frequency of wind speeds (0–3, 4–10, and >10mi/hr) and relative humidities (six classes) by visibility class (0–6 and >6 mi) and wind direction (16 points and calm) for the 3-hourly observation times of 0700, 1000, 1300, 1600, and 1900 EST for the summer season (June–September) by individual years (1962, 1963, etc.) and the combined years 1962–65 and 1966–69. In the first table, *all* observations for the period and hour were distributed according to wind direction, wind speed, and visibility. For the second table, all observations reporting no precipitation and all observations with relative humidity less than 90 percent for the reporting period and hour were also distributed by wind direction, wind speed, and visibility. In the third table, for the indicated period and hour when no precipitation was reported, all observations were distributed by wind direction, visibility, and relative humidity class (0–49, 50–59, 60–69, 70–79, 80–89, and >89 percent).

4. ANALYSIS OF DATA

From the data provided by NCC, combined frequencies of *all* 0–6 mi visibilities for the summer seasons of 1962–65 and 1966–69 were reviewed as a check on data presented in figure 1. These summarizations are presented in table 1. Without exception, the number of hours with visibilities in the 0–6-mi range was much higher during the 1966–69 period for all hours and at each location.

Charlson (1969) has suggested that visibility trend analyses should exclude observations with precipitation and/or observations with relative humidity equal to or greater than 70 percent. Following Charlson's suggestion, the percent frequencies of visibilities in the 0–6-mi range for the periods June–September 1962–65 and June–

[5] The relative humidity measurements were also examined to insure against large heterogeneities in these records. No obvious discontinuities were evident when hygrothermometers replaced psychrometers during 1963, or at any other time during the period, 1962–69.

TABLE 1.—*Frequency of 0–6-mi visibilities during the periods June–September 1962–65 and June–September 1966–69*

Period	Hours (EST)						
	0700	1000	1300	1600	1900	Total	Percent
	Akron, Ohio						
1962–65	288	159	85	70	93	695	28. 5
1966–69	364	252	150	146	160	1, 072	43. 9
	Lexington, Ky.						
1962–65	199	121	80	80	79	559	22. 9
1966–69	265	181	137	140	159	882	36. 1
	Memphis, Tenn.						
1962–65	110	83	52	40	34	319	13. 1
1966–69	151	128	73	67	53	472	19. 3

TABLE 2.—*Percent frequencies of visibilities in the 0–6-mi range after excluding hours with rain and hours with relative humidities exceeding 89 percent for the periods June–September 1962–65 and June–September 1966–69*

Period	Hours (EST)					
	0700	1000	1300	1600	1900	All
	Akron, Ohio					
1962–65	27. 3	18. 9	11. 0	6. 3	7. 8	11. 3
1966–69	37. 0	39. 0	25. 5	23. 5	23. 1	27. 3
Change	+9. 7	+20. 1	+14. 5	+17. 2	+15. 3	+16. 0
	Lexington, Ky.					
1962–65	0. 0	12. 2	9. 5	10. 0	7. 7	9. 4
1966–69	20. 0	27. 2	22. 2	22. 3	24. 6	23. 8
Change	+20. 0	+15. 0	+12. 7	+12. 3	+16. 9	+14. 4
	Memphis, Tenn.					
1962–65	0. 0	10. 0	7. 9	4. 1	3. 0	5. 8
1966–69	7. 7	17. 0	11. 2	8. 6	5. 4	10. 2
Change	+7. 7	+7. 0	+3. 3	+4. 5	+2. 4	+4. 4

September 1966–69 are given in table 2. This table shows that the proportion of observations with restricted visibility increased for all hours at all three locations from the 1962–65 period to the 1966–69 period. Furthermore, the percentages more than doubled at Akron and Lexington for all hours after the small-sample hour of 0700 EST. Memphis increases were in the same direction and only a little smaller in magnitude.

To search for meteorological factors which might account for the higher frequency of 0–6-mi visibilities during the summer seasons of 1966–69, we placed the trivariate frequency data that excluded all hours with rain and/or hours with relative humidity greater than 89 percent into sets containing:

Location
Year
Hour
Percent of wind speed (0–3, 4–10, and >10 mi/hr)
Percent of wind direction [north (NNW, N, NNE, NE); east (ENE, E, ESE, SE); south (SSE, S, SSW, SW); west (WSW, W, WNW, NW); and calm]
Percent of relative humidity (0–49, 50–59, 60–69, 70–79, 80–89)
Percent of visibilities less than 7 mi.

Hours with rain and total summer precipitation amounts were also calculated for inclusion with each set of data.

Once the data were in the above form, several multiple regression analyses (Harvey 1960) were used to sort out factors that were associated with relative frequency of visibilities in the 0–6-mi range. Factors included in our final model were subjected to an analysis of variance to determine if the percent of daylight summer visibilities in the 0–6-mi range changed significantly between 1962 and 1969. Sources of variation included in our model [complete with degrees of freedom, mean squares, and *F*-values (variance ratios)] are given in table 3.

This analysis indicates that significant differences in the percent of summer daylight visibilities in the 0–6-mi range exist due to (1) location, (2) hours (0700,1000, 1300, 1600, 1900), (3) periods (i.e., data for the years 1962–65 vs. data for the years 1966–69), (4) years within each period, (5) southerly winds, and (6) relative humidity. (The percent of visibilities in the 0–6-mi range increases with an increase in percent of SSE, S, SSW, and SW winds and decreases with an increase in the percent of low humidities.) Sources of variation that did not contribute significantly to summer visibilities in the 0–6-mi range were hours with rain and the interactions between location times period and hours times period. Thus, the difference in percent of visibilities in 0–6-mi range at specific locations or hours acts the same in both periods (1962–65 and 1966–69).

TABLE 3.—*Summary of results using analysis of variance techniques to determine if the percent of summer daylight visibilities in the 0–6-mi range changed significantly during the period 1962–69*

Source of variation	Degrees of freedom	Mean squares	*F*-values
Total	120		
Location	2	2610. 2	131. 0*
Hours	4	222. 7	11. 2*
Periods (1962–65, 1966–69)	1	3040. 4	152. 6*
Years within period 1962–65	3	205. 2	10. 3*
Years within period 1966–69	3	114. 9	5. 8*
Location × hours	8	242. 3	12. 2*
Location × period	2	39. 9	2. 0
Hours × period	4	16. 1	0. 8
Hours with rain	1	23. 5	1. 2
Percent of S(SSE,S,SSW,SW) winds	1	117. 2	5. 9*
Percent of relative humidity 0–49%	1	209. 3	10. 5*
Error	89	19. 9	

*Significant at the 0.05 level

Removal of the variation due to hour of day, wind, rain, and relative humidity resulted in 3.2–7.0-percent decreases

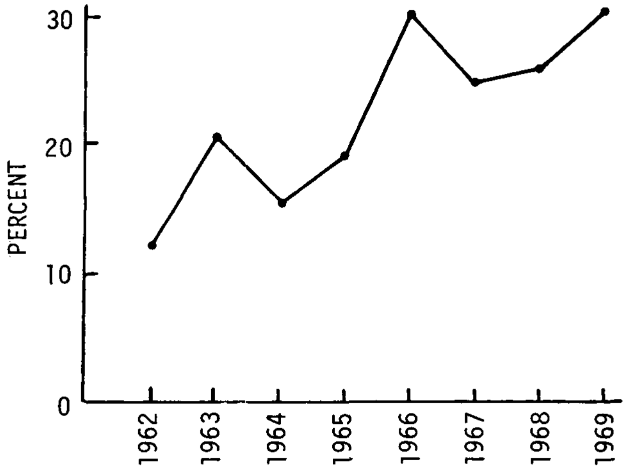

FIGURE 2.—Percent frequency of summer (June–September) visibilities in the 0–6-mi range after removal of the variation due to location, time of day, wind direction, relative humidity, and hours with rain.

TABLE 4.—*Period percent-frequencies of summer (June–September) visibilities in the 0–6-mi range for selected hours* (EST) *after removing the variation due to location, hours with rain, wind, and relative humidity*

Period	Hours (EST)				
	0700	1000	1300	1600	1900
1962–65	20. 8	17. 5	16. 2	16. 7	12. 4
1966–69	33. 8	29. 8	25. 8	27. 4	21. 4
Change	+13. 0	+12. 3	+9. 6	+10. 7	+9. 0

in 1962–65 and 1966–69 percent frequencies of visibilities in the 0–6-mi range as listed under the percent column of table 1. The decreases averaged about 4 percent at Akron and Memphis and 6 percent at Lexington. Changes in the percent frequencies of visibilities in the 0–6-mi range between the 1962–65 and 1966–69 summer periods after removal of the variation due to location, precipitation, wind, and relative humidity are given in table 4. While the greatest increases in frequency of poor visibilities between periods (1962–65 vs. 1966–69) occurred during the morning hours, substantial increases occurred at all hours. Going another step, the percent frequency of summer visibilities in the 0–6-mi range, after we removed the variation due to location, hours, wind, relative humidity, and hours with rain, was determined for each of the 8 yr, 1962–69. A plot of these annual values is shown in figure 2. A study of this figure reveals at least two items of importance: (1) the percent frequency of visibilities in the 0–6-mi range did undergo a change during the 8-yr period and (2) much of the change occurred abruptly between the summer seasons of 1965 and 1969 (i.e., data for the period 1962–65 are clustered at about 17.5 percent while the percent frequencies for 1966–69 averaged about 27.5 percent). Thus, data from the analysis of variance lead to a single conclusion.

TABLE 5.—*Percent frequencies of south winds (SSE, S, SSW, SW) during the periods June–September 1962–65 and June–September 1966–69**

Period	Hours (EST)					
	0700	1000	1300	1600	1900	All
			Akron, Ohio			
1962–65	21. 5	23. 8	24. 6	22. 7	20. 1	22. 5
1966–69	22. 9	30. 7	28. 1	28. 9	28. 9	27. 9
Difference	+1. 4	+6. 9	+3. 5	+6. 2	+8. 8	+5. 4
			Lexington, Ky.			
1962–65	25. 2	35. 9	29. 3	26. 0	26. 8	28. 6
1966–69	31. 6	35. 5	27. 5	26. 0	31. 1	30. 2
Difference	+6. 4	−0. 4	−1. 8	0. 0	+4. 3	+1. 6
			Memphis, Tenn.			
1962–65	18. 6	30. 5	29. 1	26. 2	29. 1	26. 8
1966–69	27. 8	33. 0	29. 5	27. 9	26. 8	29. 0
Difference	+9. 2	+2. 5	+0. 4	+1. 7	−2. 3	+2. 2

*Hours with rain and/or relative humidities >89 percent were excluded.

Summer daytime visibilities were significantly lower during the period 1966–69 than visibilities for the preceding 4-yr period.

5. SOUTHERLY WINDS

The analysis of variance showed that frequency of low visibilities (0–6 mi) is significantly related to southerly (SSE, S, SSW, SW) winds. A 2.2-percent increase in southerly winds in summer was associated with a 1-percent increase in daytime visibilities in the 0–6-mi range. The analysis of variance also showed hours with rain to be positively correlated with southerly winds and the percent of low relative humidities (0–49 percent) to be inversely proportional to the relative frequency of southerly winds.

Due to the significant relationship between southerly winds and low visibilities in summer, the authors thought that the percent frequencies of southerly winds (SSE, S, SSW, SW) for the hours 0700, 1000, 1300, 1600, and 1900 EST during the periods 1962–65 and 1966–69 would be of interest. Those data for Akron, Lexington, and Memphis are given in table 5. Southerly winds associated with rain and/or relative humidities equaling or exceeding 90 percent were excluded from this tabulation. Data in table 5 show slight overall increases in southerly winds during the 1966–69 periods (on Jan. 1, 1964, units for reporting wind direction changed from a 16- to 36-point scale thereby causing NCC to adopt an arbitrary scale-conversion procedure for climatic summary purposes; the net effect here appears to be one of inflating slightly the frequencies of southerly winds tallied for the second, 1966–69, period). The observed increases at Lexington and Memphis are insignificant, but those for Akron suggest further attention. Temperature anomalies and changes in mean temperature between periods (1962–65 vs. 1966–69) tend to confirm the reality of an increase in southerly winds at Akron.

If we assume that all items (see table 3) used as input into the analysis of variance are constant except for southerly winds, some inferences regarding change in visibilities due to southerly winds are possible. Since a 2.2-percent increase in southerly winds in summer was associated with a 1-percent increase in visibilities in the 0–6-mi range, changes in southerly wind percent-frequencies of +5.4 (Akron), +1.6 (Lexington), and +2.2 (Memphis) would result in 2.5-, 0.7-, and 1.0-percent increases in the percent of visibilities in the 0–6-mi range. Thus, if southerly winds were the only parameter affecting visibilities in the 0–6-mi range, they could not account for the visibility changes noted in table 4.

6. SUMMARY AND REMARKS

To verify claims of increased duration and extent of haze over the eastern United States, we checked horizontal surface visibilities during summer at the Akron-Canton Airport for its period of record (1954–69). These records show that a rapid deterioration in summer visibilities began in 1966 and has continued through 1970. Data from Akron, Lexington, and Memphis at hours 0700, 1000, 1300, 1600, and 1900 EST were obtained from NCC. The data included frequencies related to specified visibilities, wind direction and speed, and relative humidity classes for the summer seasons of 1962-69. Results obtained after subjecting the NCC frequency data to analysis of variance confirmed that the percent of poor visibilities (less than 7 mi) was greater during the period 1966–69 than during 1962–65.

Meteorological variables do not account for the visibility changes noted in this study. Air-quality data is insufficient for use in determining possible changes in air pollution levels during the 1960s. The meager air-quality data available for analysis do not totally support the contention that foreign airborne materials might have caused the changes in visibility that are reported here. For example, Spiratas and Levin (1970) have reported definite downward trends in the amount of suspended particulate matter at downtown sampling stations throughout the United States.

Since the Spiratas and Levin findings are limited to suspended particulates, the authors cannot rule out other forms of atmospheric pollution as contributing factors to changes in visibility during the 1962–69 period. It therefore appears that the increased frequency of summer visibilities in the 0–6-mi range during the period 1966–69 must be caused by (1) natural phenomena, (2) an increase in aerosol or air pollution loadings, or (3) a combination of aerology and items 1 and/or 2. Unfortunately, the authors' literature review suggests that data are insufficient to favor one of these explanations at present, but we hope that the statistical results presented here will stimulate photochemical research and standardized tropospheric monitoring and analysis.

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